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(54) UV and plasma stable high-reflectance multilayer dielectric mirror.

(57) An improved high reflectance multilayer dielectric mirror in which the final layers (12) are of a UV stable material such as HfO_2/SiO_2 or ZrO_2/SiO_2 which final layers are deposited over the TiO_2/SiO_2 layers (10).

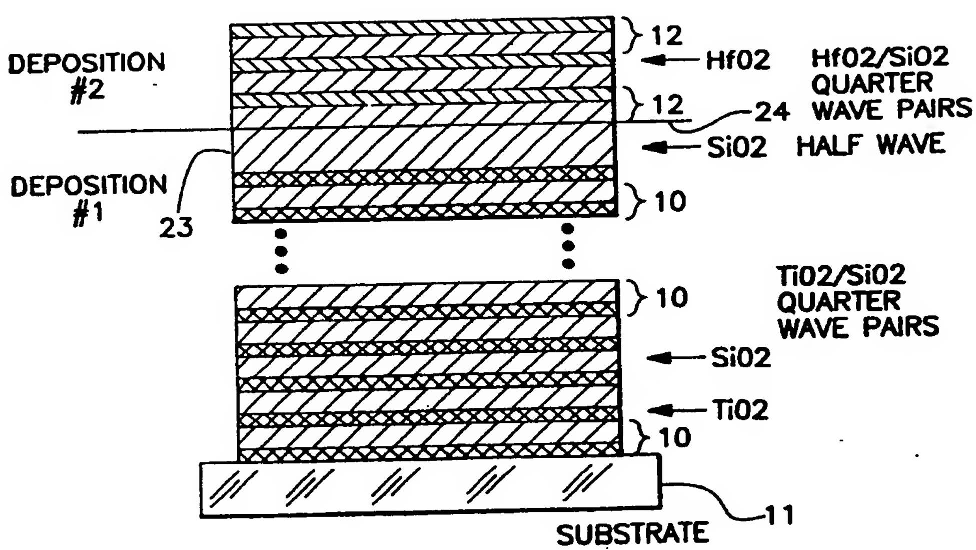

Fig. 1

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UV AND PLASMA STABLE HIGH-REFLECTANCE MULTILAYER DIELECTRIC MIRROR

BACKGROUND AND SUMMARY OF THE INVENTION

This invention is directed to improved multilayer dielectric mirrors, particularly for use in ring laser angular rate sensors (ring laser gyros).

Ring laser gyro mirrors are exposed to ultraviolet (UV) and plasma from the gyro He-Ne plasma. The gyro mirror multilayer dielectric materials commonly in use, that is, TiO_2/SiO_2, is sensitive to both in ways which degrade mirror reflectance and thus deleteriously affect gyro performance. The problem of UV-induced mirror loss changes is generally a small effect generating loss changes in the range of 10-100 ppm (parts per million). The problem of plasma-induced loss changes is one which ultimately appears to affect mirror lifetime and can ultimately give rise to large loss changes. Only in applications such as the ring laser gyro where the mirrors are directly in a He-Ne plasma, the mirror reflectances are very high in the range of 99.99% and the reflectances must be stable over long periods are these considerations important. If UV effects were encountered in a conventional mirror material, a standard solution would involve fabricating an entire mirror from a different UV stable material.

This invention describes using a UV sensitive series of (high index/low index) quarter wave pairs to provide the rapid gain in mirror reflectance and uses a second series of UV insensitive (high index/low index) quarter wave pairs on top of the stack to improve the mirror UV properties. An example of the UV and plasma insensitive material is hafnium oxide (HfO_2) or zirconium oxide (ZrO_2). To fabricate a full mirror out of HfO_2/SiO_2 pairs would require on the order of 40 layers depending precisely on the refractive index and desired reflectance levels. To achieve comparable reflectance levels with improved UV stability with the present invention requires only about 28 layers, that is three HfO_2/SiO_2 layer pairs on eleven TiO_2/SiO_2 layer pairs. The reducing of the time required for depositing materials can be critical in making low defect, high reflectance mirrors for use in ring laser gyros. Increased deposition time required by more layers increases the chance for system arcing due to several causes. For yield considerations, to fabricate good mirrors, it is necessary to keep the deposition time to a minimum. The present invention combines the high reflectance gain generated by using high index materials with the UV and plasma stability of outer layers of high band gap materials to provide a mirror much less sensitive to the gyro environment which can more quickly be fabricated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a pictorial view of the base mirror layer design according to the invention.

FIGURE 2 is a graphical disclosure of calculated reduction of UV-induced loss changes for TiO_2/SiO_2 mirrors when HfO_2/SiO_2 pairs are added.

FIGURE 3 is a graphical presentation of typical plasma-induced loss change for ion beam TiO_2/SiO_2 mirrors with various SiO_2 thicknesses.

FIGURE 4 is a graphical presentation of plasma-induced loss change for ZrO_2/SiO_2 and HfO_2/SiO_2 stacks deposited on a TiO_2/SiO_2 mirror.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

High reflectance multilayer dielectric mirrors are well known in the art, and find use particularly in the construction of laser gyros and ring laser gyros. A high reflectance mirror of this type is formed by depositing thin films of high/low refractive index pairs until a certain reflectance level is reached. An example is shown in FIGURE 1 where a plurality of TiO_2/SiO_2 quarter wave pairs 10 are deposited on a substrate 11. In this example, the TiO_2 is the high index material and the SiO_2 is the low index material. Table 1 below lists the refractive index of several materials used in this invention. The ratio of the index of TiO_2 to that of SiO_2 is high so that the reflectance level increases rapidly with a minimum number of layer pairs, such as eleven pairs, for example.

High index materials such as TiO_2 have low energy band gaps making them susceptible to UV degradation in the laser and also from plasma-induced loss centers at RLG operating wavelengths.

Table I

	Refractive Index	Band Gap	
		eV	k(P)
TiO_2	2.45	3.5	3500
SiO_2	1.46	>7	<1800
HfO_2	2.1	5.5	2250
ZrO_2	2.15	5.0	2500

UV radiation from the ring laser gyro plasma environment can penetrate into the mirror layers and generate absorption sites for the RLG 633nm radiation. These UV-induced reflectance changes effect the long term stability of gyro performance. The plasma-induced loss changes effect mirror lifetime and are generally believed to be caused by plasma-induced formation of electron or hole traps from which absorption at 633nm can occur. High energy band gap materials are not as susceptible to UV but because of their lower refractive index, require a larger number of layers to achieve high reflectance levels. In addition, the strong bonding of oxygen in highly insulating ZrO_2 and HfO_2 films make them more stable than TiO_2 against stoichrometric changes and electronic charge migration generated via plasma interaction. In this invention there is described a UV and plasma insensitive mirror design in which the high reflectance levels are achieved while still keeping the number of mirror pairs as low as possible.

Referring again to FIGURE 1, there is disclosed a first deposition of a number of quarter wave pairs 10 of TiO_2/SiO_2 on a suitable substrate 11, such as low expansion glass which suitably matches the thermal coefficient of the laser block (not shown). As an example, the TiO_2 and SiO_2 layers may be on the order of 700 P (angstroms) and 1100 P, respectively. This first deposition of TiO_2/SiO_2 pairs is followed by or continued with a second deposition of quarter wave pairs 12 of HfO_2/SiO_2 or ZrO_2/SiO_2. This design utilizes the fact that the top material HfO_2 or ZrO_2 has a large band gap and is not as effected by UV or plasma but has a lesser refractive index than TiO_2 requiring more layers to achieve the same mirror reflectance if used throughout. The underlying high index material such as TiO_2, has a high refractive index and therefore achieves high reflectance levels with fewer film layers but is sensitive to UV. By this two deposition structure taught herein which overcoats the TiO_2/SiO_2 layers with the HfO_2/SiO_2 or ZrO_2/SiO_2 layers, the UV sensitive material is buried in the stack and the mirror sensitivity to the UV is reduced, while the total layer count is maintained low.

For the standard prior art TiO_2/SiO_2 mirror, the UV radiation from the He-Ne plasma between 3000 and 4000 angstroms is absorbed mostly in the first few TiO_2 mirror layers: HfO_2/SiO_2 or ZrO_2/SiO_2, on the other hand, do not absorb this radiation nor transmit it to the underlying TiO_2 film. The exact profile depends on mirror material band gaps, absorption coefficients and UV wavelengths. The He-Ne 633nm laser fields in the mirror materials are reduced by 25-50% with each succeeding pair depending on mirror material. Since the UV-induced absorption at any one place in the mirror is proportional to bE^2, the product of UV-induced absorption coefficient and field strength squared, by burying the UV-absorbing TiO_2 film, it is possible to reduce the UV mirror sensitivity. Qualitatively by selecting the outer mirror materials so that wherever E is large, b is small, it is possible to reduce UV mirror sensitivity. FIGURE 2 shows the calculated reduction of UV-induced loss changes for standard TiO_2/SiO_2 mirrors when one and three $HfO_2(n=2.1)/SiO_2(1.46)$ pairs are added. These reductions assume no UV sensitivity in the top materials and are calculated relative to an estimated standard UV sensitivity of 60 ppm. This calculation is compared with data taken with one and three HfO_2/SiO_2 and ZrO_2/SiO_2 pairs on a $TiO_2(n=2.45)/SiO_2$ mirror.

Referring more specifically to the first and second deposition described in FIGURE 1, the first deposition of the TiO_2/SiO_2 layer pairs continues until a certain reflectance is reached (i.e., a reflectance of 99.99%, for example). The second high index/low index deposition of HfO_2/SiO_2 or ZrO_2/SiO_2 material can be deposited on top of the existing stack until the final desired reflectance is achieved. Alternately, if the deposition system does not have the capability of sputtering three different materials, a half wave low index film 23 can be added as shown in FIGURE 1 to both protect the high index TiO_2 film from degradation and provide a low field surface interface which is insensitive to loss changes induced by surface contamination. In a second deposition system, the second deposition of HfO_2/SiO_2 or ZrO_2/SiO_2 pairs can be added as shown. The advantage of depositing a half wave of SiO_2 is that the region 24 between the two SiO_2 films is a low field interface and this reduces the effect of up-to-air contamination on mirror absorption.

FIGURE 3 is a graphical presentation showing a typical plasma-induced loss change for ion beam TiO_2/SiO_2 mirrors with various SiO_2 thicknesses. Along the ordinate is plotted loss change in PPM (parts per million) and along the abscissa is plotted accumulated plasma exposure in hours.

FIGURE 4 is a graphical presentation showing absolute plasma-induced loss changes for three layer pairs of either ZrO_2/SiO_2 or HfO_2/SiO_2 stack deposited on a TiO_2/SiO_2 mirror. Along the ordinate is plotted mirror loss change in ppm and along the abscissa is plotted total plasma exposure in hours. Noteworthy is the lack of any dramatic increase in loss compared to TiO_2/SiO_2 mirrors even though the high index HfO_2 or ZrO_2 film is exposed directly to the plasma.

Claims

1. A high-reflectance multilayer dielectric mirror comprising a mirror substrate (11); and
a first plurality of UV sensitive high index/low index dielectric quarter wave layer pairs (10) deposited on said substrate: **characterized by**
a second plurality of UV insensitive high index/low index dielectric quarter wave layer pairs (12) deposited over said first layer pairs.

2. An ultraviolet-resistant mirror according to claim 1, **characterized in that** said first plurality of thin film quarter wave layer pairs (10) consists of TiO_2/SiO_2 and said second plurality of dielectric thin film quarter wave layer pairs (12) is selected from the UV insensitive group consisting of HfO_2/SiO_2 and ZrO_2/SiO_2.

3. An ultraviolet-resistant mirror according to claim 1 or 2 for use in a He-Ne plasma environment, which plasma includes undesirable UV emanations, in particular for use in a 633 nm He-Ne laser environment, **characterized by** the mirror comprising

a) a mirror substrate (11);

b) a first high refractive index dielectric material (TiO_2). which material has a low energy band gap making it susceptible to UV degradation;

c) a second somewhat lower high refractive index dielectric material (HfO_2), which material has a high energy band gap making it UV insensitive;

d) a low refractive index dielectric material (SiO_2);

e) a plurality of thin film quarter-wave layer pairs of said first high index and said low index materials (10), deposited on said substrate (11), said pairs having a rapid gain in mirror reflectance, but being UV sensitive; and

f) a second plurality of thin-film quarter-wave layer pairs of said second high index and said low index materials (12) deposited over aforesaid pairs to increase said reflectance while not being affected by said UV emanations, whereby aforesaid pairs are shielded from UV.

4. The mirror according to claim 1, 2 or 3 in which said second layer pairs consist of ZrO_2/SiO_2.

5. The mirror according to claim 1, 2 or 3 in which said second layer pairs consist of HfO_2/SiO_2.

6. The mirror according to one of the preceding claims, **characterized in that** the TiO_2 and SiO_2 layers are on the order of 700 angstroms and 1100 angstroms, respectively.

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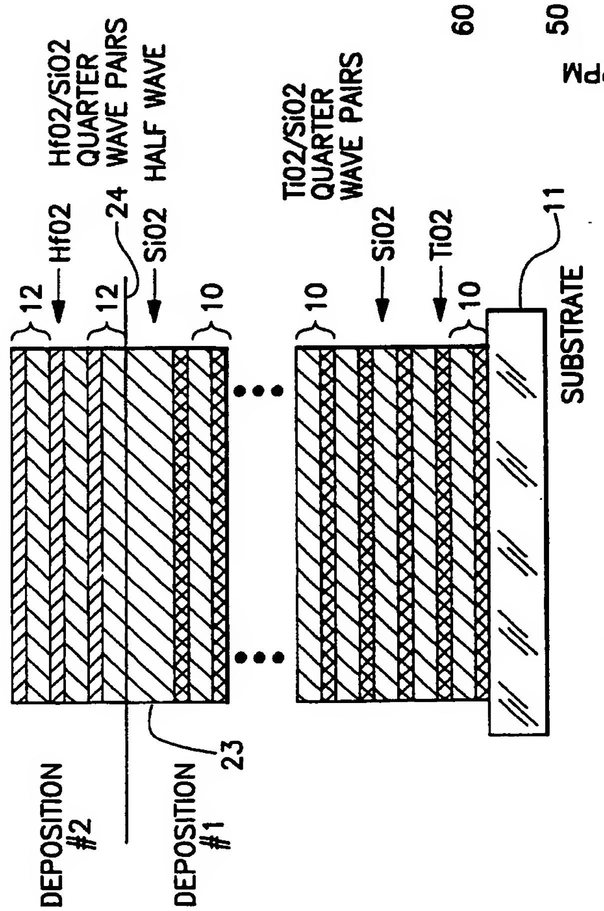
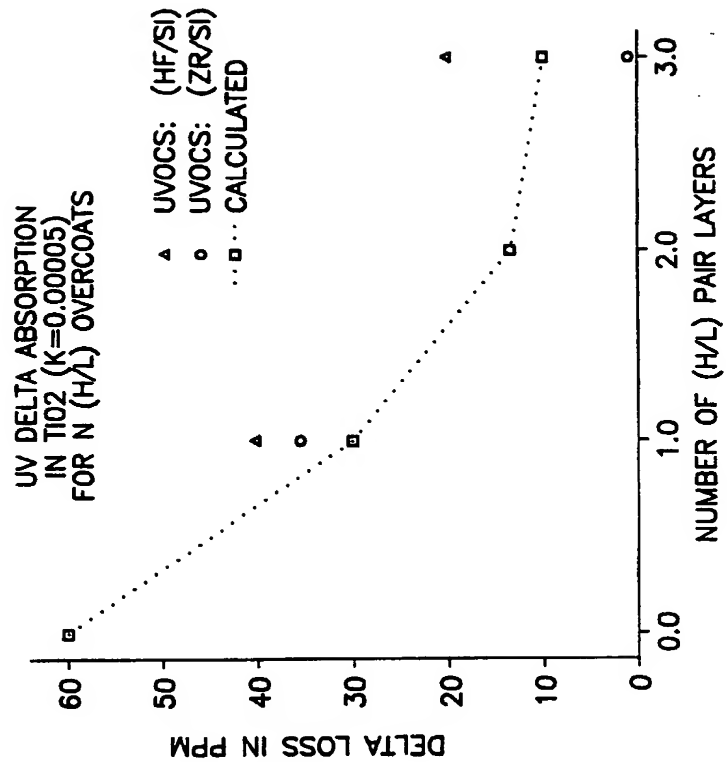


Fig. 1

Fig. 2



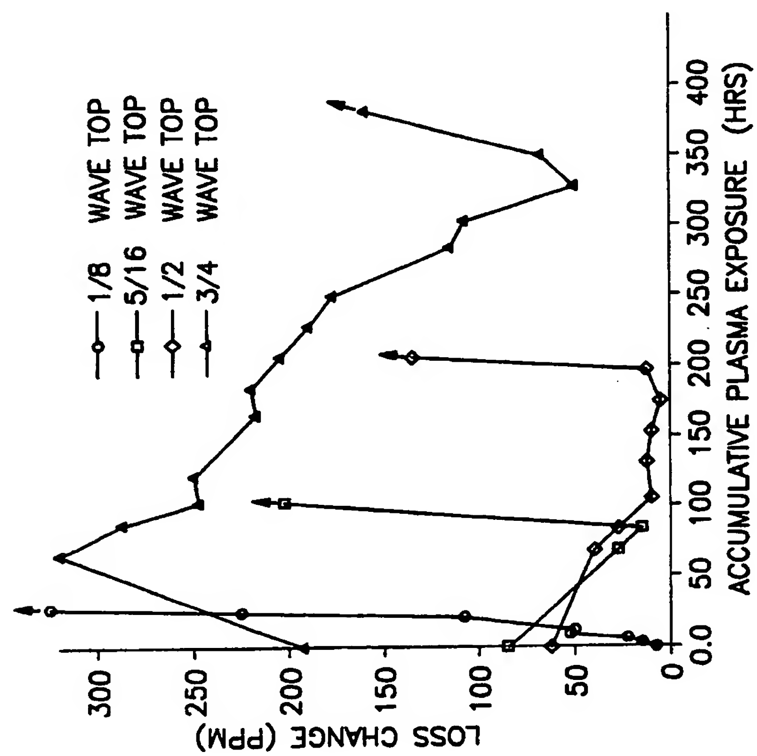

LOSS CHANGE (PPM)
ACCUMULATIVE PLASMA EXPOSURE (HRS)
1/8 WAVE TOP
5/16 WAVE TOP
1/2 WAVE TOP
3/4 WAVE TOP

Fig. 3

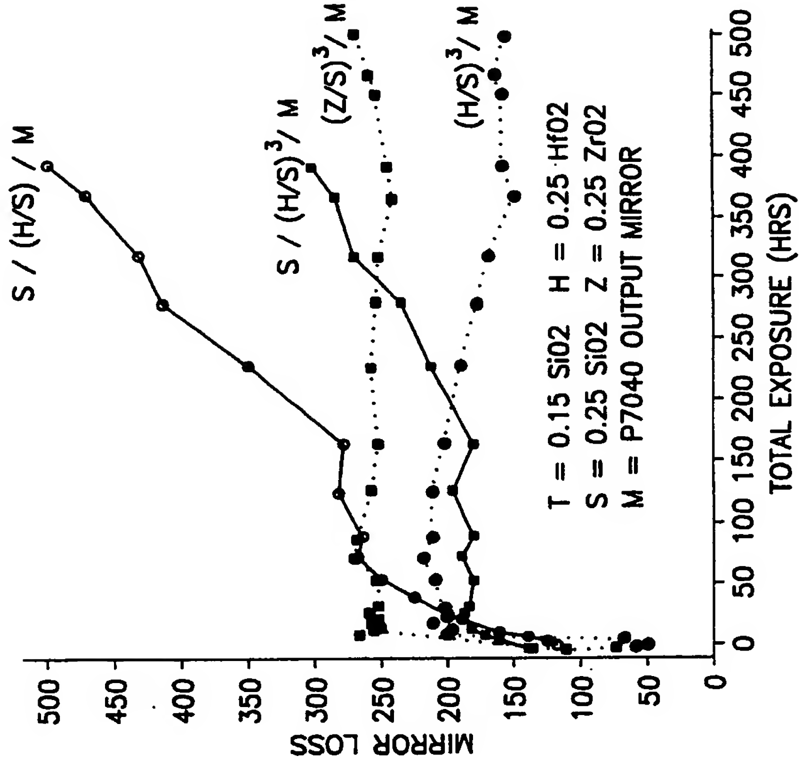

MIRROR LOSS
TOTAL EXPOSURE (HRS)
S / (H/S) / M
S / (H/S)^3 / M
(Z/S)^3 / M
(H/S)^3 / M
T = 0.15 SiO2 H = 0.25 HfO2
S = 0.25 SiO2 Z = 0.25 ZrO2
M = P7040 OUTPUT MIRROR

Fig. 4